Arterial and venous repair with vascular clips: Comparison with suture closure

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Purpose: **Nonpenetrating, arcuate-legged titanium vascular closure staple (VCS) clips were initially developed for microvascular anastomoses with little experience of their use in larger vessels. The purpose of this study was to compare the VCS clips with standard suture closure of arteriotomies and venotomies in common iliac vessels of pigs.**
Methods: **In nine pigs, longitudinal 1 cm iliac arterial and venous incisions were repaired with VCS clips on one side and continuous 6-0 polypropylene suture on the other, and the macroscopic and microscopic results were assessed after 3 months.**
Results: **The time required for vessel repair was significantly shorter with clips than with sutures both in arteries (51 ± 9 vs 414 ± 36 seconds) and in veins (100 ± 32 vs 439 ± 45 seconds). There was no significant difference in the inner diameter, intimal thickness, or intima-to-media height ratios of the arteries or veins after either method of closure.**
Conclusions: **Repair of 1 cm incisions in small-diameter arteries and veins with VCS clips results in wound healing as good as that achieved with standard suture closure, when assessed for patency, leakage, degree of narrowing, and intimal reaction. The time required for clip closure is considerably shorter than for suture closure. (J Vasc Surg 1997;26:24-8.)**

Since the first reported permanent anastomosis of a blood vessel by Eck in 1877, the contributions of Jassinowsky, Dörfler, Briau, and Jabolay and Watts in the development of successful methods of suture, and the painstaking work of Carrel and Guthrie from 1905 to 1912, the principal methods of vascular repair, such as triangulation of the vessel and intima-to-intima approximation by means of everting sutures, were established.[1]

In 1955, Samuels[2] introduced a method of vascular repair by means of V-shaped stainless steel clips and used them in the closure of longitudinal arteriotomy wounds and single and double anastomosis of the aorta in dogs. The clip repair was thought to be more rapid than previous methods and adhered to the requirement of good vascular anastomosis. The clips, however, never gained wider use in vascular surgery.

In the 1980s, a new, nonpenetrating, arcuate-legged titanium vascular closure staple (VCS) clip was developed by Kirsch and others for brain vascularization by the superficial temporal artery–middle cerebral artery anastomosis and has subsequently been used in experimental studies to perform different types of microvascular anastomoses.[3,4] Although there is less experience of the use of these VCS clips in larger blood vessels, they have several potential benefits: the VCS clip cinches the vessel wall, everting but not penetrating the endothelium, yet grasping the adventitia firmly without crushing.[3] The use of nonpenetrating clips could reduce factors associated with increased risk of intimal hyperplasia, such as operative trauma, mural ischemia, and platelet deposition.

In our preliminary study using VCS clips in the closure of linear incisions in the pig aorta and inferior vena cava, we showed that clip closure is easy and fast to apply and safe in short-term (1 month) follow-up.[5] The purpose of this study was to compare the VCS clips with standard suture closure of arteriotomies and venotomies, with special reference to clamping and closure times, degree of narrowing,

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Table I. Closure and clamp times with VCS clips or continuous polypropylene sutures (n = 9 in each group)

	Artery		*Vein*	
	VCS clip	*Suture*	*VCS clip*	*Suture*
Closure time (sec)	51 ± 9	414 ± 36*	100 ± 32	439 ± 45*
Clamp time (sec)	156 ± 18	511 ± 35*	290 ± 43	604 ± 52*

*$p < 0.05$ (VCS clip vs suture).

Table II. Inner diameter with VCS clips or continuous polypropylene sutures

	Artery		*Vein*	
	VCS clip	*Suture*	*VCS clip*	*Suture*
Inner diameter (mm)	3.2 ± 0.1	2.9 ± 0.3	4.1 ± 0.3	3.8 ± 0.3
% of uninjured vessel	107 ± 3	95 ± 6	100 ± 1	95 ± 3

and development of intimal hyperplasia during a longer follow-up period of 3 months.

MATERIAL AND METHODS

Nine Yorkshire pigs weighing 27 to 38 kg were used. Animal care complied with the "Principles of Laboratory Animal Care" (formulated by the National Society for Medical Research) and the *Guide for the Care and Use of Laboratory Animals* (NIH Publication No. 86-23, revised 1985).

The VCS clips are manufactured by the United States Surgical Corp. (Norwalk, Conn.) and are currently available in three sizes; large (clip dimension at the tip, 2.0 mm), medium (1.4 mm), and small (0.9 mm).

All nine pigs were subjected to midline laparotomy under general isoflurane anesthesia and aseptic conditions. For infection prophylaxis, the pigs received one dose of ceftriaxone sodium (1 g intravenously) at the beginning of the operation. At operation, both common iliac arteries and veins were exposed and 2500 IU of heparin was given intravenously. All four vessels were sequentially doubly clamped, and an anterior 1 cm incision was created between the clamps and repaired. The method of repair was randomly assigned to closure with VCS clips on one side and continuous 6-0 polypropylene sutures on the other side. Large VCS clips (6 to 14 per wound, mean 8.3) were used for arterial repair, and medium-sized clips (6 to 12 per wound, mean 9.1) were used for venous repair. All vessel closures were performed by the same surgeon after a period of practicing the clip closure in other animals.

The pigs were observed for a mean of 86 days (range, 75 to 97 days), underwent reoperation under general anesthesia for assessment of vessel patency and harvesting the repaired vessel specimens, and were killed—while still under anesthesia—using saturated potassium chloride.

The harvested vessels were opened longitudinally at the opposite site of the repair, and the repair site was assessed for irregularities ("bridges" and "pockets," defined as steep transverse or curved formations interrupting the smooth wound line at the intimal site) and bare clips under an operating microscope. The inner diameter was calculated from the inner circumference of the vessel measured at the narrowest site of the repair and, in addition, calculated as a percentage of the inner diameter of the uninjured part of the vessel (mean of diameters measured from uninjured parts proximal and distal to the injured part). The tissues were fixed in formalin, and the clips were removed by microdissection. Multiple sections of the specimens were taken for histologic examination using standard hematoxylin-eosin staining and were reviewed by a pathologist (N.F.) to assess the quality of healing at the repair sites, and to measure intimal thickness and the intima-to-media height ratio for determining the degree of intimal hyperplasia.

The data are presented as mean ± SE, and a *t* test (or Mann-Whitney rank sum test, if assumptions for parametric test were violated) was used for statistical analysis, with significance at the 0.05 level.

RESULTS

The times required for closure of the vessel incisions, as well as total clamp times, are shown in Table I.

All 36 vessels in the nine pigs were patent after 3 months. None of the repairs showed signs of thrombosis or defective closure (pseudoaneurysms or arteriovenous fistulas). The inner diameter of the vessels was slightly, but not statistically significantly, larger after closure with VCS clips both in arteries and veins and were not narrowed when compared with the uninjured part of the vessel (Table II).

An irregular intimal surface with bridges and pockets were seen in one of nine arterial wounds closed with clips and in three of nine wounds closed with sutures. All clips were covered with intima. In the veins, one bare clip projecting to the lumen was seen in two of nine venous repairs with clips, but the

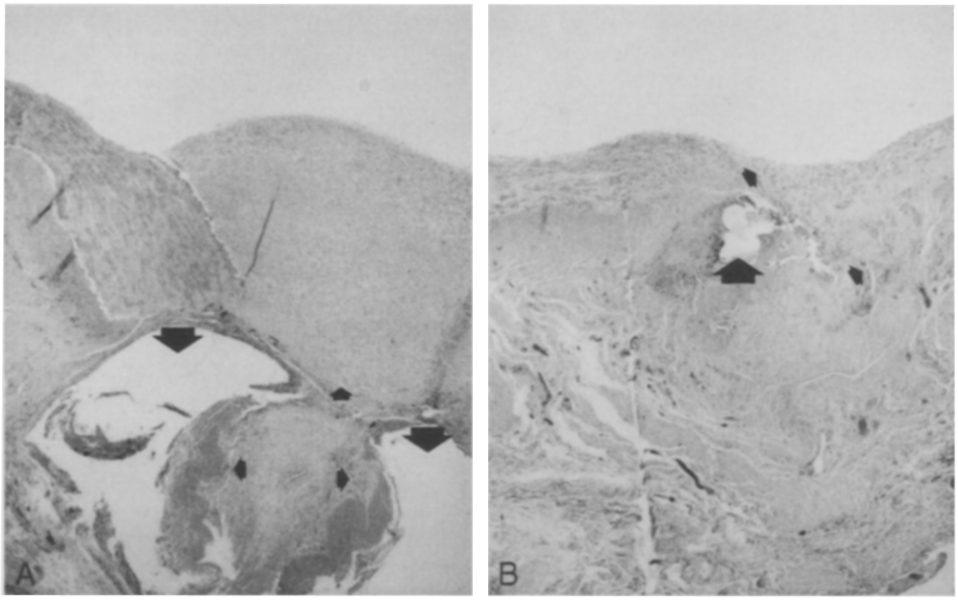

Fig. 1. A, Transverse section of a linear arteriotomy, intimal side on top, after clip closure (hematoxylin-eosin staining; magnification, ×20). Note empty crescent-shaped area previously occupied by clip *(large arrows)* and remnants of everted vessel edges with thick, smooth-surfaced intimal layer *(small arrows)*. **B,** Transverse section of a linear arteriotomy, intimal side on top, after suture closure (hematoxylin-eosin staining; magnification, ×20). Well-healed incison *(small arrows)* can barely be identified in the middle, surrounding an empty subintimal space *(large arrow)* previously occupied by the suture.

Table III. Intimal thickness and intima-to-media height ratio with VCS clips or continuous polypropylene sutures

	Artery		*Vein*	
	VCS clip	*Suture*	*VCS clip*	*Suture*
Intimal thickness (μm)	100 ± 6	105 ± 5	17 ± 2	15 ± 1
Intima-to-media height ratio	0.88 ± 0.10	1.08 ± 0.21	0.17 ± 0.03	0.11 ± 0.01

surfaces were otherwise smooth. In three of the nine veins closed with sutures, intimal pockets were seen at the repair site.

All arterial wounds were well healed, with minimal reactive changes consisting of foreign-body giant cells and scattered lymphocytes (Fig. 1, *A* and *B*). There was no significant difference in the intimal thickness or the intima-to-media height ratio between vessels closed with sutures or clips (Table III).

All venous wounds were well healed, with few foreign-body giant cells and no inflammation (Fig. 2, *A* and *B*). All vessels showed mild to moderate intimal hyperplasia (intima-to-media height ratio, 0.05 to 0.5), with no significant difference regarding the method of closure (Table III).

DISCUSSION

In this experimental study, closure of longitudinal iliac arteriotomies and venotomies in pigs with VCS clips resulted in wound healing as good as that of standard closure with polypropylene sutures when assessed for vessel patency, leakage at the closure line, degree of narrowing of the vessel diameter, and intimal reaction. In spite of the everted closure with clips, there was no narrowing of the vessel diameter (Table II). Although the inner diameter at the clip closure site was slightly larger than at an uninjured part of the vessel, there were no indications for pathologic processes such as early aneurysmal dilatation. Although not measured in this study, previous studies using the VCS clips for microvascular anasto-

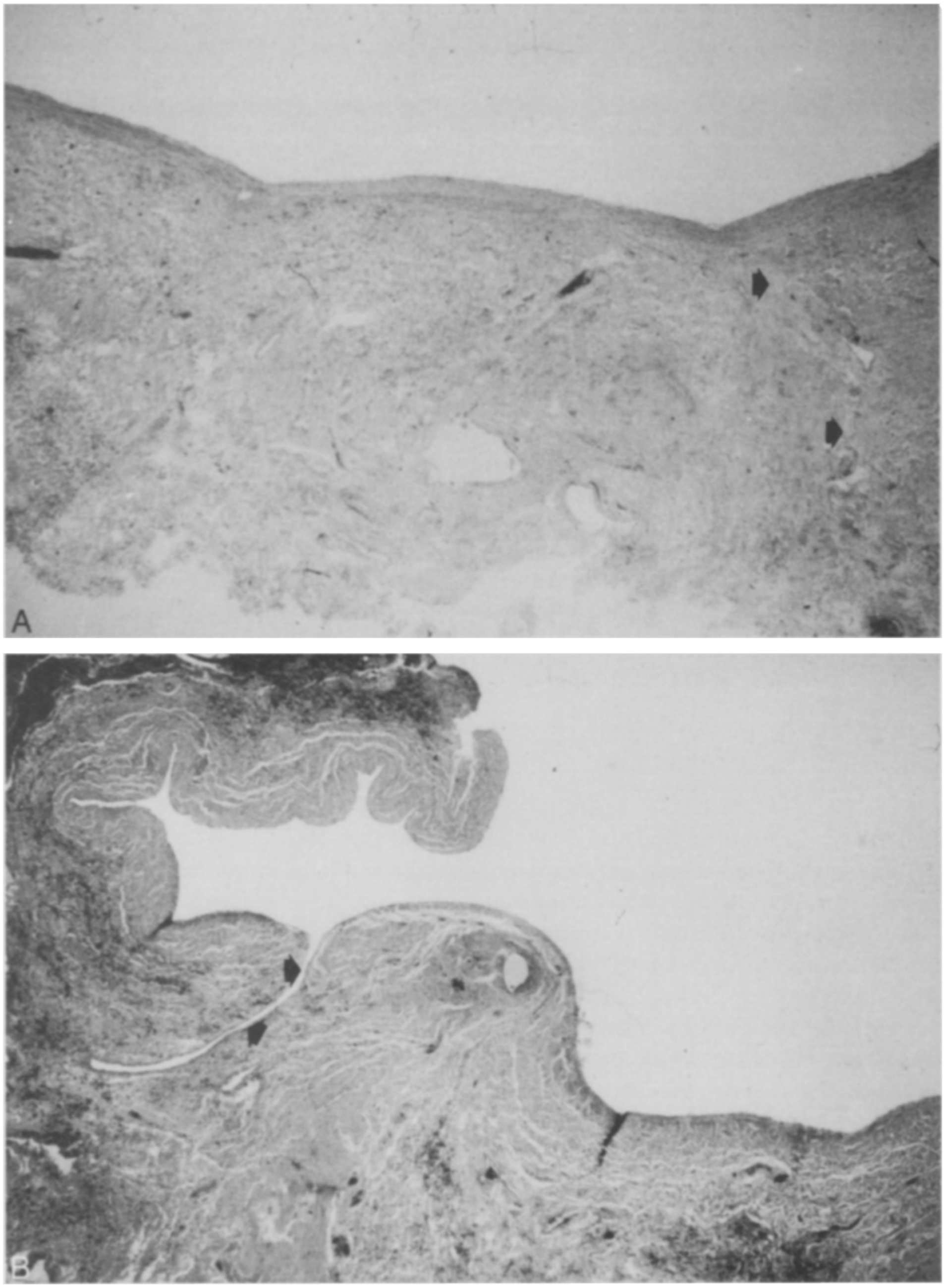

Fig. 2. A, Transverse section of linear venotomy, intimal side on top, after clip closure (hematoxylin-eosin staining; magnification, ×20). Venous incision *(arrows)* is well healed with smooth intimal surface. **B,** Transverse section of linear venotomy, intimal side on top, after suture closure (hematoxylin-eosin staining; magnification, ×20). Note irregular surface contour of the intimal layer *(arrows)*.

moses have shown that the mechanical properties of the clipped anastomoses are equivalent or superior to results with microsuture.[4]

In this study, the intimal surface was smooth in most cases after clip closure. Although there was one clip devoid of intimal cover in two veins repaired with clips, there was no thrombosis, in contrast to cases where silver clips have been found to rotate into the lumen and a thrombus has developed around them.[2] The absence of bare clips after thicker-walled arterial repair and the minimal degree of inflammation around the clips would suggest that the occurrence of bare clips after venous repair was caused by a technical error—the inability to grasp and align the thin venous walls accurately for clips-closure—rather than pressure necrosis causing the migration of the clip into the lumen.

In his pioneering studies with metal clips for vascular reconstruction, Samuels[2] showed that silver clips cause more perivascular and suture-line fibrosis narrowing the lumen than stainless steel clips, even when applied in everting, nonpenetrating fashion. In our previous study using the titanium-based VCS clips for closure of longitudinal aortotomies and inferior caval venotomies in a pig, the specimens showed residual neovascularization and bridging of the incision with collagen and fibroblasts 1 month after the injury.[5] In this study, there were minimal reactive changes and virtually no inflammation in the vessel wall 3 months after clip closure, confirming the inert nature of the titanium clips in the tissues.

Intimal hyperplasia is widely recognized as a significant factor in the late failure of vascular reconstructive procedures and may be related to operative trauma, mural ischemia, compliance mismatch, flow disturbances, platelet deposition, and foreign body reaction in vascular tissue incited by permanent nonabsorbable suture materials.[6] It has been suggested that intimal hyperplasia is reduced after the everted, nonpenetrating clip closure, as compared with standard suture closure in which the full thickness of the vessel is penetrated by the needle, although the difference can be demonstrated only after 1 year.[7] In this study, the intimal thickness and intima-to-media height ratios were not significantly different after closure with clips or sutures after 3 months (Table III), suggesting that at this time point there was no benefit of the clips compared with sutures with regard to the development of intimal reactions.

Although the healing properties were more or less equal after closure with either method, there was a significant difference in the speed with which the clips could be applied when compared with suture repair (Table I). Even when the time to create the vessel wound, obviously same in both closure methods, was included in the total clamp times, the clip-closure resulted in clamp times of only one-third that of suture closure in arteries and one-half that of closure in veins. The difference in the actual closure times was even larger; the clip closure required only approximately 1 minute in arterial repair and 2 minutes in venous repair, whereas suture repair required about 7 minutes in both vessels. The shorter time of arterial compared with venous repair with clips probably reflects the easier manner with which the thicker-walled artery can be grasped and aligned for clip closure. There were no tears or other complications that prolonged the application times of clips in veins. The application of the clips is easy and can be mastered by most surgeons after a very short learning period. The virtues of speed are obvious on many occasions of vascular reconstruction.

The potential vascular applications of the clips are numerous.[2] They could be used for quick and safe repair of injured vessels after military and civilian vascular injuries. Because they can be applied in confined spaces, they could be used for surgical emergencies, such as inadvertent incision of blood vessels or closure of arterial stumps too short for ligature. Any vascular procedure in which the length of clamp time is critical could possibly be made safer with the use of clips. With the advance of endoscopic vascular procedures, in which suture reconstruction is cumbersome and sometimes impossible, the clips could be used for easy vascular reconstruction.[8] A potential disadvantage of the use of vascular clips could be in their poor ability to close injuries or perform anastomoses in heavily diseased arteriosclerotic vessels, but this requires further study. Also, the need to place a significant amount of staples in larger repairs or circumferential anastomoses would require some increased technical manipulation, which could limit the use of clips in the repair of larger defects.

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